

## DEVELOPMENT OF A HIGH TEMPERATURE STATIC STRAIN SENSOR\*

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## INTRODUCTION

The goal of this program is to develop an electrical resistance strain gage system which will accurately measure the static strains of superalloy blades and vanes in gas turbine engines running on a test stand. Accurate knowledge of these strains is essential to reaching the goals of the Host program in the selection and experimental verification of the various theoretical models developed to understand and improve the performance of these engines.

The specific objective of this work is to develop a complete system capable of making strain measurements of up to  $\pm 2000$  microstrain with a total error of no more than  $\pm 10$  percent of full scale during a 50 hour period at temperatures as high as 1250 K. In addition to survival and stability, attaining a low temperature coefficient of resistance, of the order of 20 ppm/K or less, was a major goal. This requirement arises from the presently unavoidable uncertainties in measurement of the exact temperatures inside gas turbines for use in making corrections for apparent strain due to temperature.

## EXPERIMENTAL FACILITIES

The thermal cycling apparatus shown in figure 1 was used to make resistance measurements up to 1250 K at constant temperatures or at heating and cooling rates as high as 250 K/min. The sample, which is positioned axially in the center of a split metal tube heater, can be either in the form of an end to end strip or as a gage installed on a substrate with both of the electrical connections at the same end. The system also includes an external plenum, not shown in figure 1, to permit cooling gases to be introduced at lower temperatures for better temperature control and, in addition, a computer system with special features to obtain accurate resistivity data at high speeds.

## SENSOR PROPERTIES

In previous alloy development work (refs. 1,2) the Pd-13Cr (in weight %) alloys was identified as the best alloy candidate available for use at these temperatures in terms of stability and reproducibility. Regardless of the rates of heating and cooling, this alloy always shows a very linear resistivity versus temperature behavior. This indicates that the Cr is always in complete solid solution and that no ordering or second phases are formed at any temperature in this system. Although the addition of Cr dramatically lowers the

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thermal coefficient of resistivity compared to that of pure Pd, this coefficient is still too high for this application. In order to reduce the thermal sensitivity to acceptable levels, the thermally compensated design shown in figure 2 was developed. The strain sensitive resistive element in the center of the gage is still 3 mm x 3 mm as defined by the program goals but symmetrical outlying grids have been added to provide thermal compensation. These additional low resistance compensation grids of Pd or Pt have high temperature coefficients of resistance and are relatively strain insensitive. Because all of these resistive elements show linear resistance versus temperature behavior, this compensation should apply over the full temperature range of interest.

An important feature of the PdCr alloy was that it should be inherently self protective with regard to oxidation. At exposed surfaces, the Cr oxidizes to form an adherent scale of  $\text{Cr}_2\text{O}_3$  to protect the Cr electron scattering centers dissolved in the alloy beneath the oxide from further oxidation. The earlier conclusions about the stability and repeatability of the resistance of the PdCr alloy was based on measurements made using 0.46 mm (460  $\mu\text{m}$ ) thick metal strips of the alloy prepared by drop casting followed by grinding and annealing. A primary objective this year was to verify that this good behavior remained when the alloy was prepared as an even thinner film prepared by sputtering. Sputtering is the preferred fabrication technique for actual gages because of good bonding and the ability to form well-bonded undercoats of alumina insulation films using the same process.

One of the problems with sputtering is that the material is deposited as nodules which must be separated by boundaries with significant misorientations which should provide paths for fast diffusion. The concentration of these boundaries and the potential for these boundaries to be unstable during the use of this material as a strain gage can be avoided by annealing. We have determined that these films can be recrystallized by a 12 hour heat treatment in argon ( $1 \times 10^{-5}$  ppm  $\text{O}_2$ ) at 1420 K. An unfortunate side effect of this treatment was the observation that the resultant films sometimes contain holes. Figure 3 shows a severe example of this effect. It is believed that these holes are caused by the loss of some of the much larger nodules which always seem to be present in these films. It is believed that the loss of these nodules may be related to differential thermal expansion stresses set up between the substrate and the overlying films during heating and cooling.

Experimental data on the effect of sensor thickness on the stability of resistance at 1250 K in air is presented in figure 4. The material for the 50  $\mu\text{m}$  thickness was prepared by splat quenching while that at the 6.5  $\mu\text{m}$  thickness was prepared by sputtering on top of sputtered alumina on a Hastelloy X substrate. Due to an error by the vendor in preparing the target, the sputtered samples also contained approximately 5 wt percent Al as an impurity replacing some of the Pd. All of these samples were heated for at least 10 hours at 1250 K in air prior to drift testing in order to form stable oxide surface scales.

The rate of drift of the sputtered film, even with only one side exposed to oxidation, is unacceptable for our use. Measurements of the thermal coefficient of resistivity of this film gave results which indicated that most of the Cr and Al in the film had been lost. When the material is this thin, most of the oxide forming elements must apparently be consumed in order to form the protective scale. The reason why the resistance of the intermediate thickness film increased rather than decreased with time is not clearly understood. It may indicate the operation of a fundamentally different oxidation process.

Experience with the fabrication of sputtered resistive grids has shown that it is difficult to make films thicker than 6.5  $\mu\text{m}$  when the spacing between the individual grid resistors is as small as 76  $\mu\text{m}$ . The high strength of the PdCr films makes it difficult to break the unwanted film loose along the lines separating the film sputtered on the photo resist and that on the part. Although recent work has indicated that we may be able to

make thicker deposits by using thicker masks, it also rapidly becomes more difficult to develop the desired level of total grid resistance with this small a grid area if thicker films are used. Avoiding this problem by increasing the voltage across the sensor increases the probability of voltage breakdown across the insulation layer and causing unacceptable levels of self-heating of the gage.

## PROTECTIVE OVERCOATS

Attempts have been made to completely or significantly seal the exposed sputtered PdCr surfaces by forming an additional top overcoating of alumina. It is recognized that aluminum oxide would be a superior film to prevent oxidation. The diffusion of Cr is relatively rapid through its oxide and Cr can form volatile oxides ( $\text{Cr}(\text{OH})_2$  and  $\text{CrO}_3$ ) which do not form in the case of alumina. Attempts to oxidize sputtered aluminum overcoats in place were not particularly successful because the aluminum oxide formed was so impervious to any further oxidation. Figure 5 shows "spurs" of alumina formed along the edges of PdCr resistive grid lines. Apparently the aluminum melted, the volume expansion ruptured the thin oxide surface, and more oxidation occurred until all of the aluminum metal was oxidized or dissolved in the alloy. Current experimental approaches to identify the optimum top coating configuration are summarized in Table 1. In some of these experiments, the alumina is being sputtered with the substrate heated to reduce the maximum tensile forces that could be generated in these films by the differential thermal expansions between the oxide and the Hast X substrate.

## REFERENCES

1. Hulse, C. O.; Bailey, R. S.; and Lemkey, F. D.: High Temperature Static Strain Gage Alloy Development Program, NASA CR-174833, March 1985.
2. Hulse, C. O.; Bailey, R. S.; and Grant, H. P.: The Development of a High Temperature Static Strain Gage System. Turbine Engine Hot Section Technology 1985, NASA CP-2405, pp. 45-49.

## HIGH SPEED THERMAL CYCLE- RESISTANCE MEASUREMENT APPARATUS

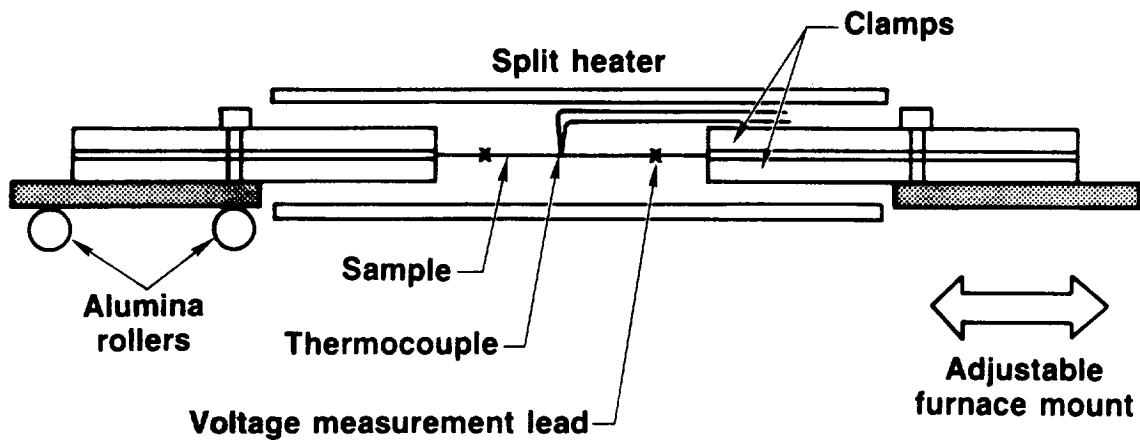


Figure 1

## THERMALLY COMPENSATED STRAIN GAGE GRID DESIGN

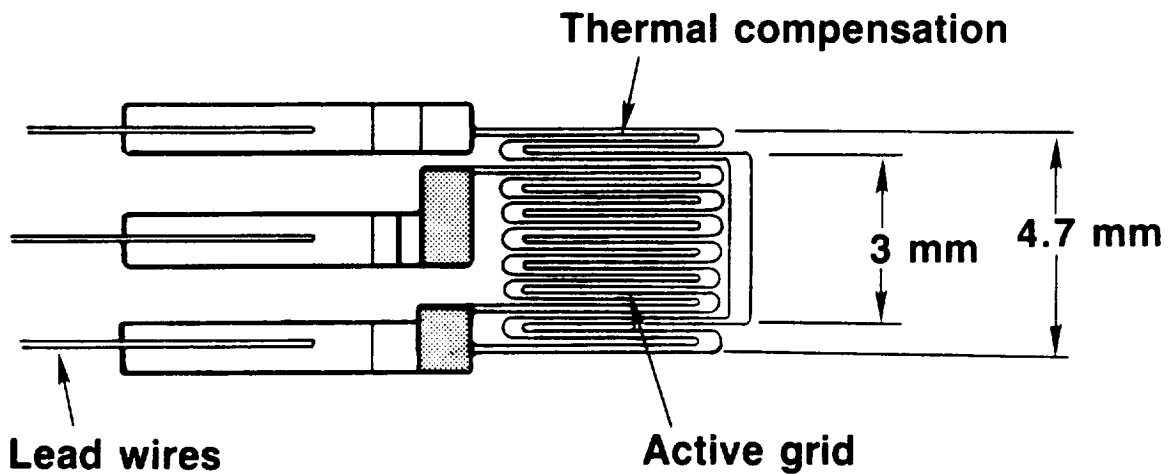


Figure 2

## HOLES IN SPUTTERED PdCr FILMS AFTER RECRYSTALLIZATION

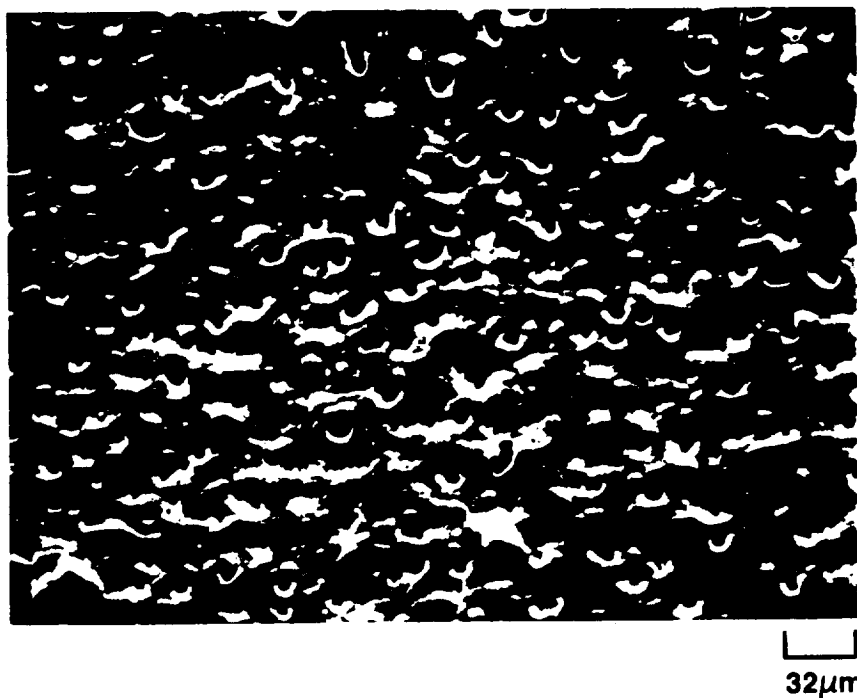


Figure 3

## EFFECT OF FILM THICKNESS ON DRIFT IN RESISTANCE OF Pd-13 wt % Cr

(1250 K in air for 50 hours)

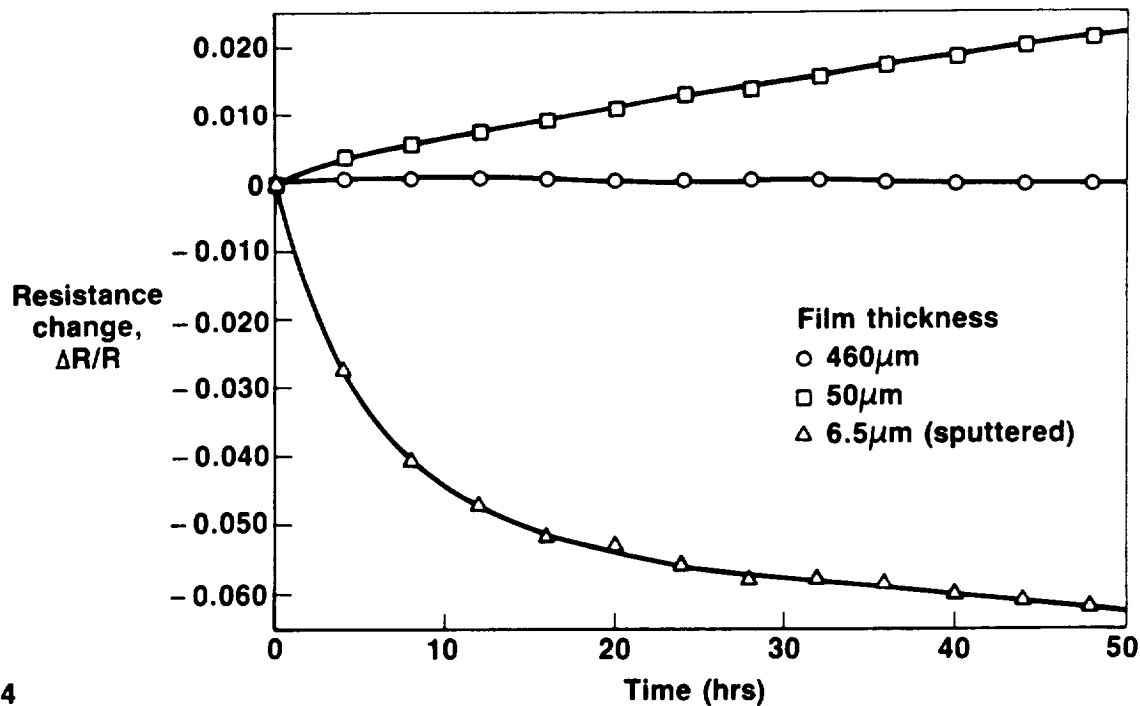


Figure 4

# EDGE PROTRUSIONS ON PdCr GRID AFTER OXIDATION OF 0.5 $\mu$ m Al OVERCOAT

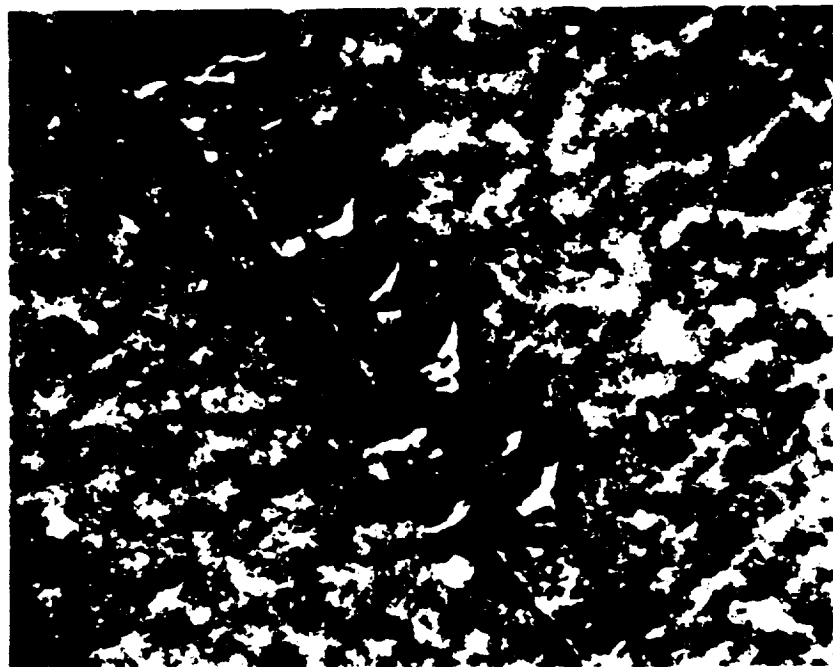


Figure 5

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OF POOR QUALITY

0.02 mm

## TABLE I STRAIN GAGE OVERCOAT SYSTEMS

Type	Sensor PdCr	Sputtered					Transfer tape Glass
		Al <sub>2</sub> O <sub>3</sub>	FeCrAl	Pt	Glass	Al	
1	X	X					
2	X	X	X				
3	X	X		X			
4	X	X			X		
5	X	X				X	
6	X	X					X